Signature of a Quarkyonic Phase in the QCD Phase Diagram

Ágnes Mócsy
Pratt Institute, Brooklyn, NY
Pratt

in collaboration with Paul Sorensen (BNL)

CPOD @ BNL June 2009

Baryon-Baryon Correlations
as Signature of 1st Order Phase Transition in Heavy Ion Collisions

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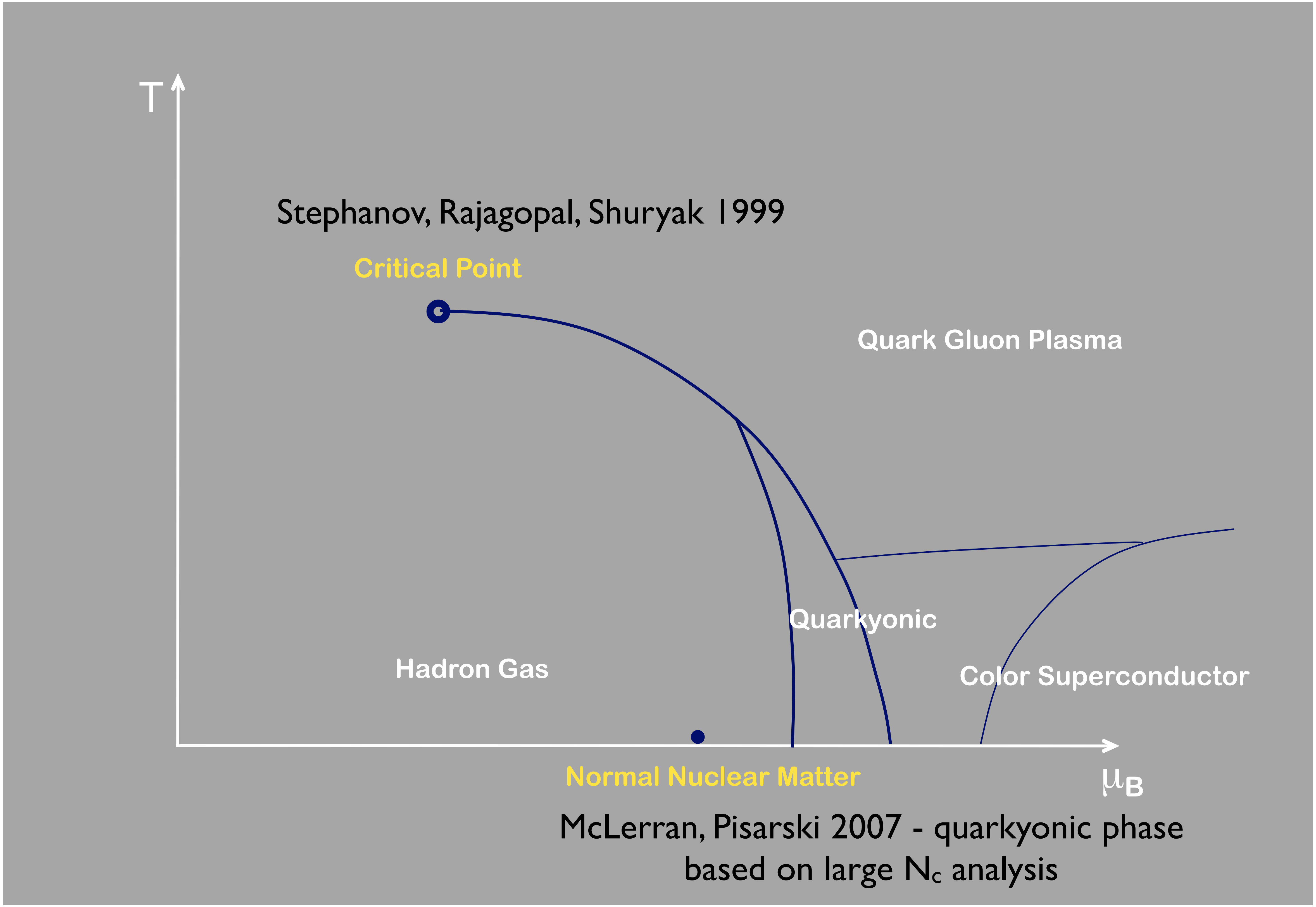
In this talk

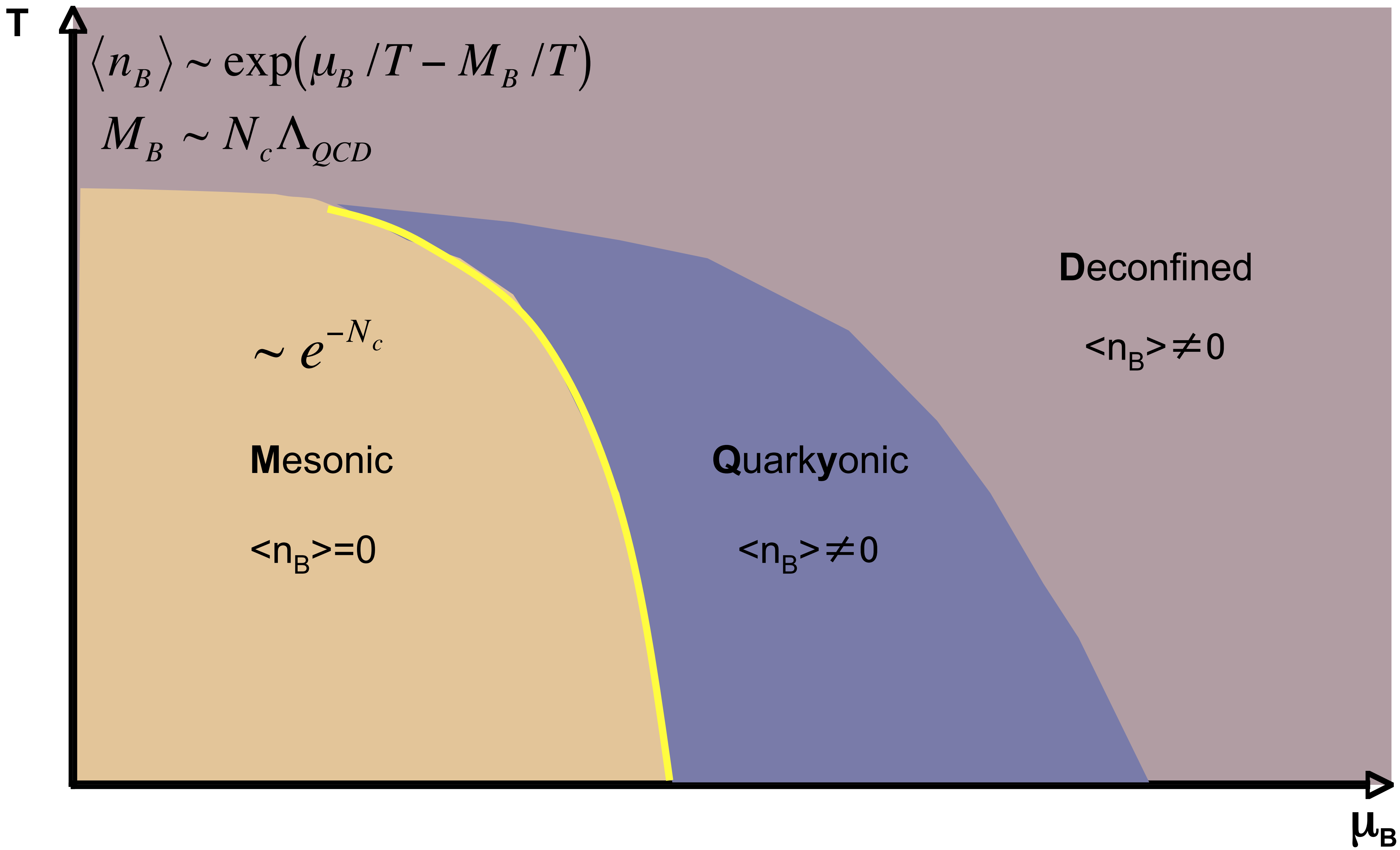
- Motivation to look for baryon-baryon correlations
- Our Bubble Monte-Carlo Blast-Wave Model
- Correlation results: mapping the parameter space
- Implications for experiments

QCD Phase Diagram



Quarkyonic Phase

Baryon number order parameter for 1st order transition - Hidaka, McLerran,Pisarski 2008



crossing a transition with a jump in baryon number (very small to finite) leads to baryon rich cluster formation

Quarkyonic Phase

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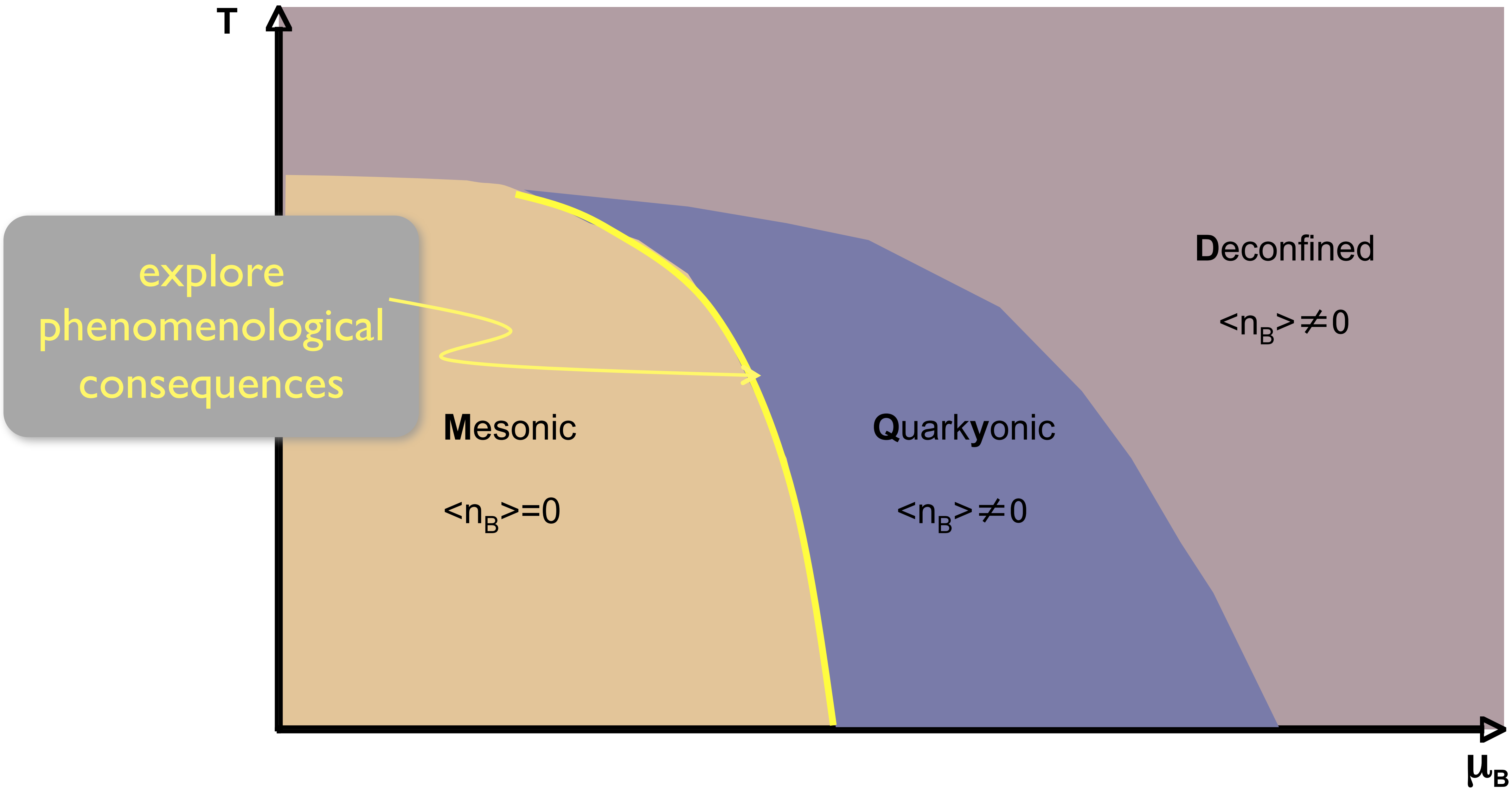
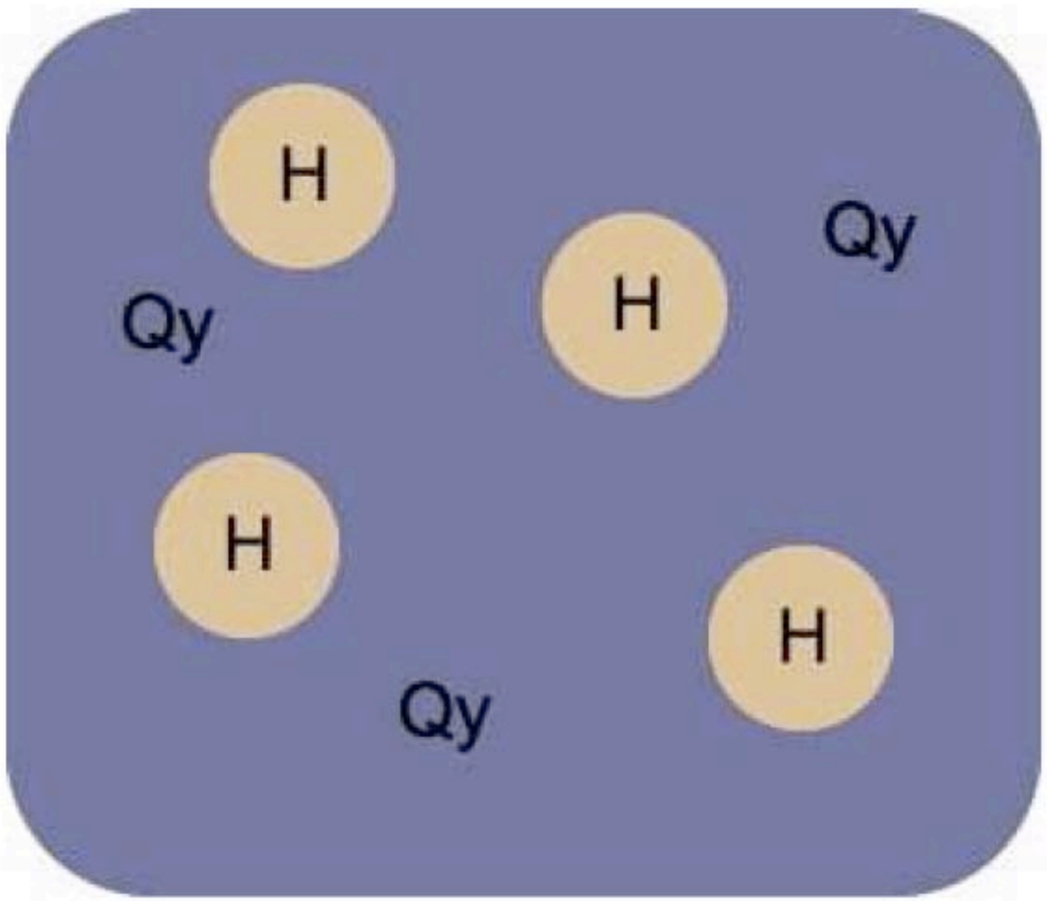


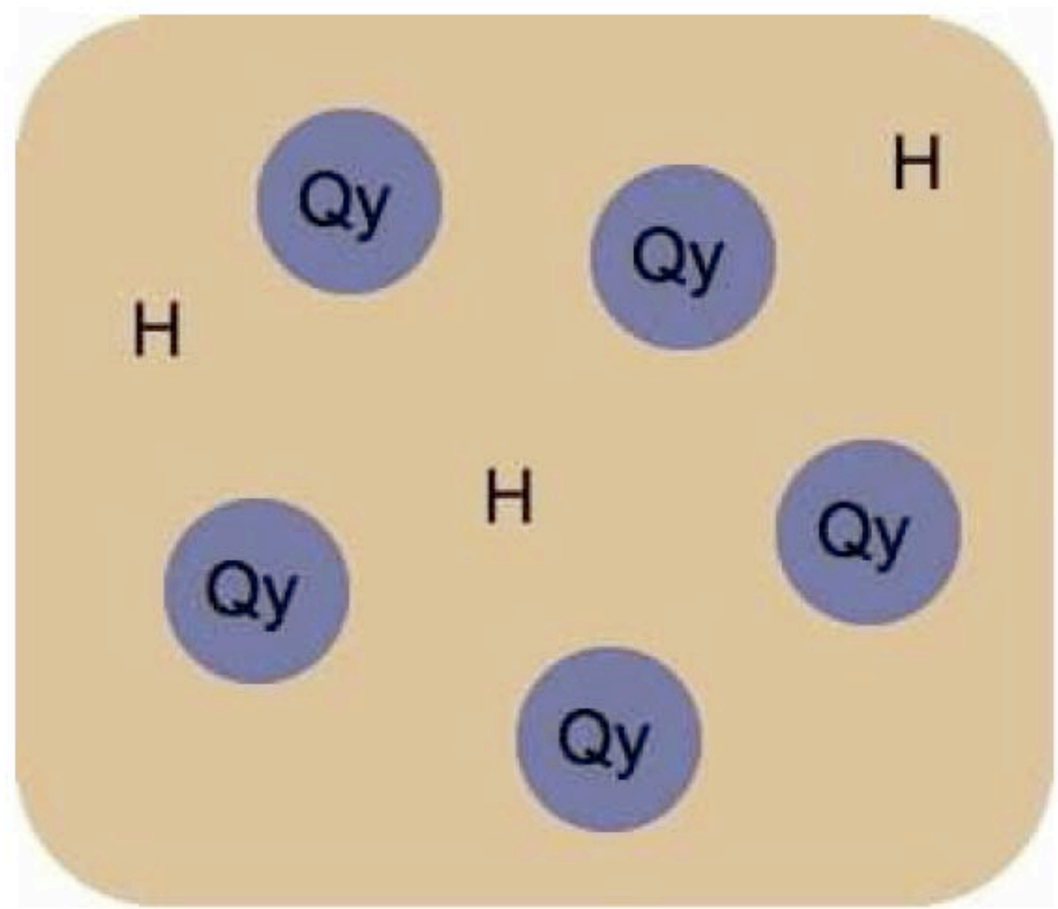
crossing a transition with a jump in baryon number (very small to finite) leads to baryon rich cluster formation

note: we explore observables different from baryon number fluctuations

Bubble Nucleation

1st order transition from quarkyonic to mesonic phase goes through nucleation





- Baryons trapped in quarkyonic bubbles during transition
- Flow can translate spatial correlations to momentum-space

Generic for 1st order transition between baryon rich and baryon poor phases

Similar to Gavin 2001, but we consider momentum space correlations
Also see Randrup, consequences of spinodal break-up

The Phenomenology:
Bubble Monte-Carlo Blast-Wave

- Generate N_B total baryon number in an event

$$dN/dN_B \sim exp\{-(N_B - \bar{N}_B)^2/2\bar{N}_B\}$$

- Generate n_B number of baryons per bubble

$$dN/dn_B \sim exp\{-(n_B - \bar{n}_B)^2/2\bar{n}_B\}$$

- Distribute bubbles in coordinate space

longitudinal: flat distribution
transverse: center & surface density profile

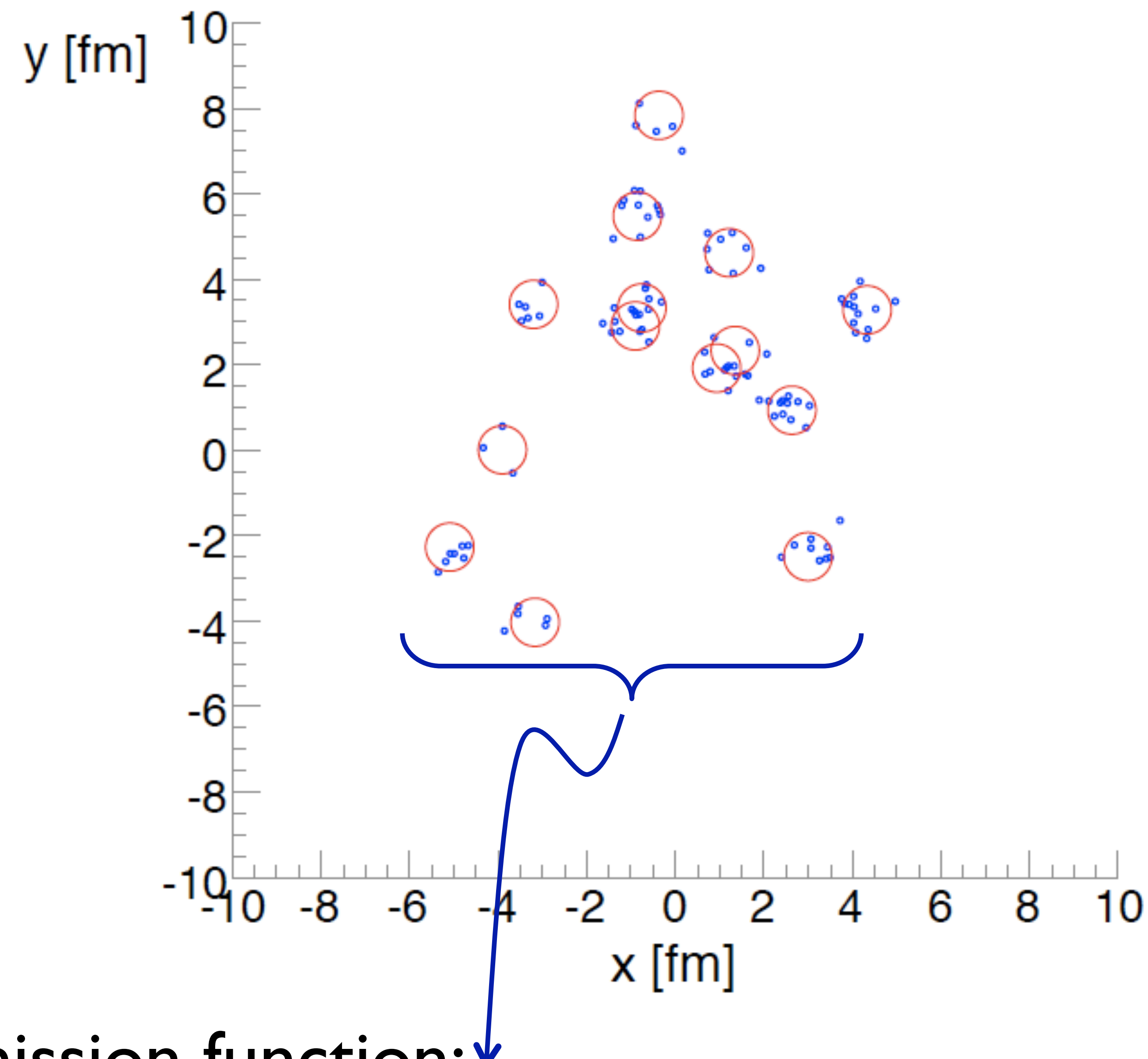
- Distribute baryons inside bubbles

$$dN/dxdydz \sim 1/(1 + \exp\{-(r_{bubble} - R)/a\})$$

$$r_{bubble} = 0.6\ \mathrm{fm}(n_B)^{1/3} \qquad a = r_{bubble}/8$$

Spatial Correlations

Study how spatial correlations manifest in momentum space



Use discrete set of MC baryons as the source Ω in a blast-wave

Input spatial points and radial boost; blast-wave returns probability of momentum coordinates

caveats: 1) instantaneous boost can violate causality 2)no momentum conservation

Emission function:

$$S = m_T \cosh(\eta - Y)\Omega(r,\phi_s)\sum_{n=1}^{\infty}(-1)^{n+1}e^{na\cos(\phi_s-\phi_p)}e^{-nb\cosh(\eta-Y)}$$

radial boost: $\beta = \beta_0 r$

Lisa, Retiere 2003

Correlation Studies

Look at baryon-baryon correlations vs relative angle ($\Delta\varphi$ and $\Delta\eta$) based on the variable

$$\boxed{\frac{\Delta\rho}{\sqrt{\rho_{ref}}} = \frac{\rho - \rho_{ref}}{\sqrt{\rho_{ref}}}}$$

Normalization assures independence of total number of baryons per event N_B

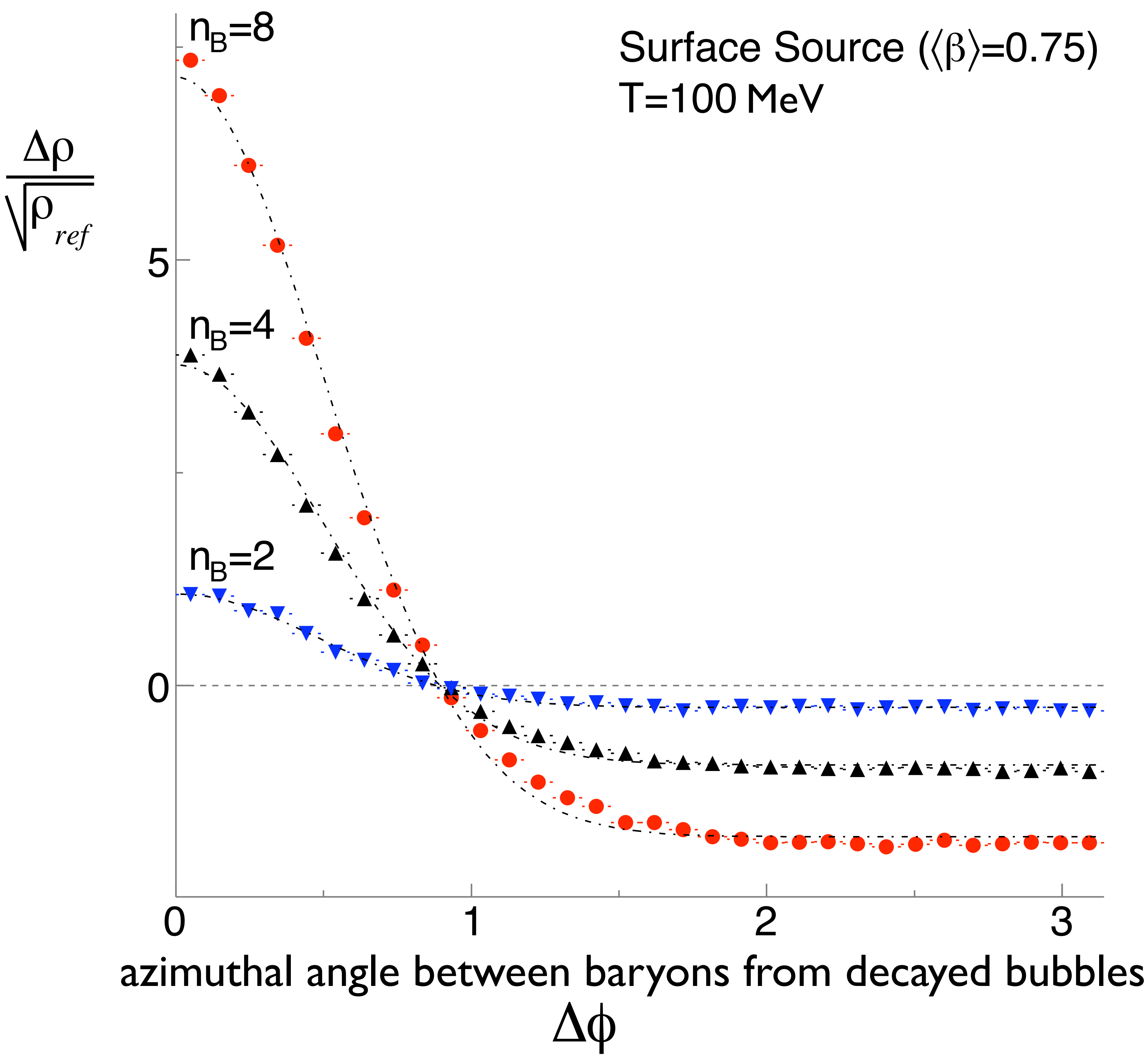
ρ = pair density

ρ_{ref} = product of single particle densities

We study dependence on average number of baryons per bubble n_B
a range of radial flow β and bubble decay temperature T
& emission geometry Ω

Our study neglects global fluctuations. We focus on the shape of the correlation function.

Varying no. Baryons per Bubble



bubble nucleation + flow leads to small angle correlations

good description by gaussian

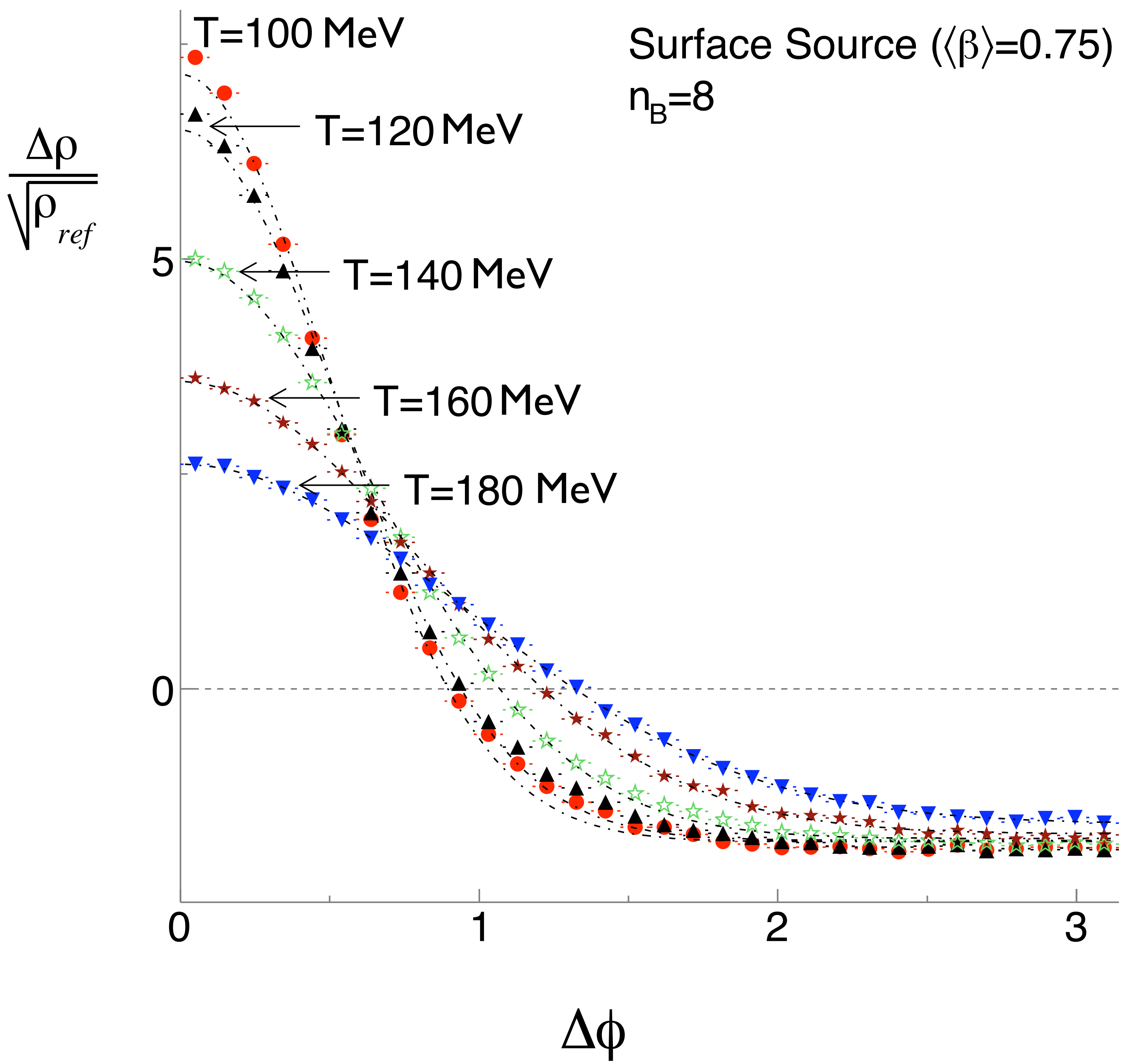
- amplitude A, rms σ

correlation grows as $n_B - 1$

assumptions:

- all baryons come from bubbles (no dilution from background)
- strong flow and low temperature at time of bubble decay

Temperature Dependence



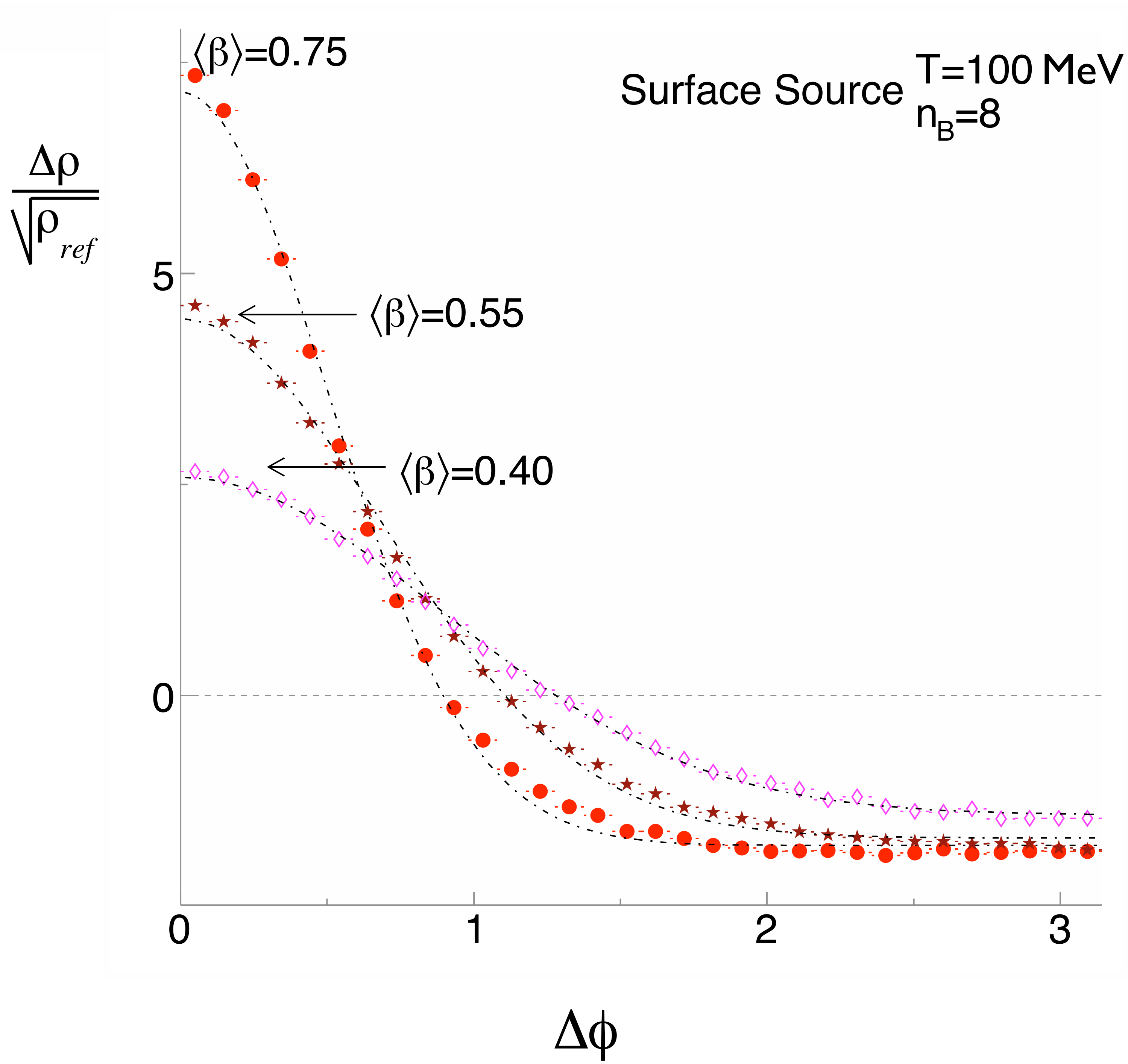
Correlation is weaker for bubbles decaying at higher temperature

Competition between T and boost from flow

A phase transition at higher T will be harder to detect

Pocket formula: $\sigma = 0.694 - 0.00639 * T + 0.0000435 * T^2$

Radial Flow Dependence



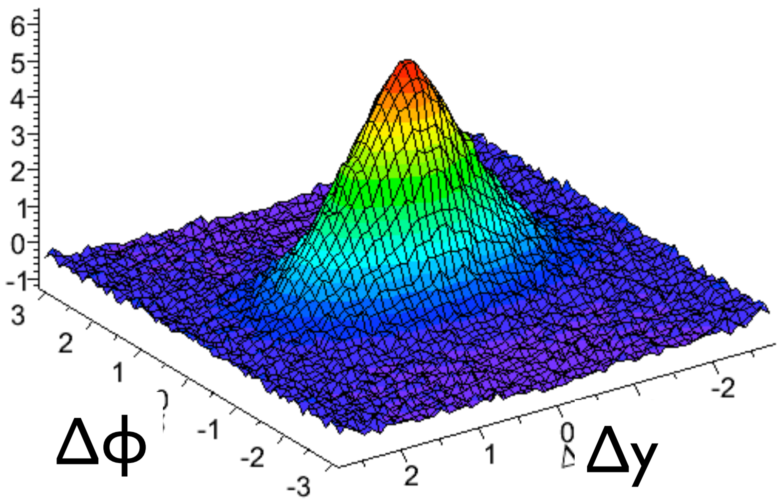
Flow is required to convert coordinate-space correlations to momentum-space

Correlation is stronger for bubbles with larger boost

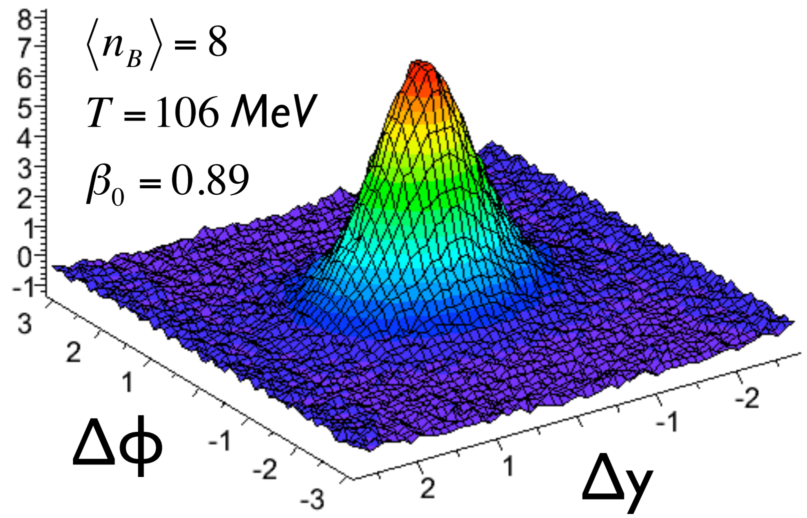
An early phase transition, at T before flow develops will be hard to detect

Pocket formula: $\sigma \approx 1.357 - 1.367 \times \langle \beta \rangle$ valid for $0.29 < \langle \beta \rangle < 0.75$

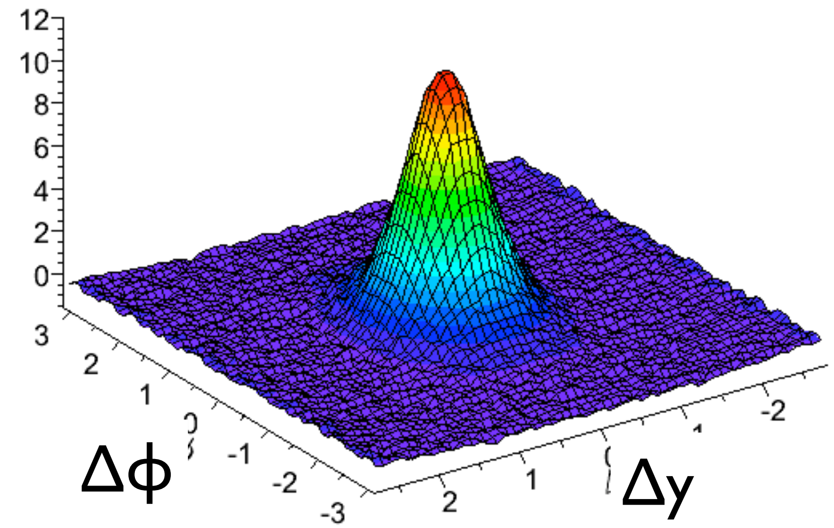
Longitudinal Width



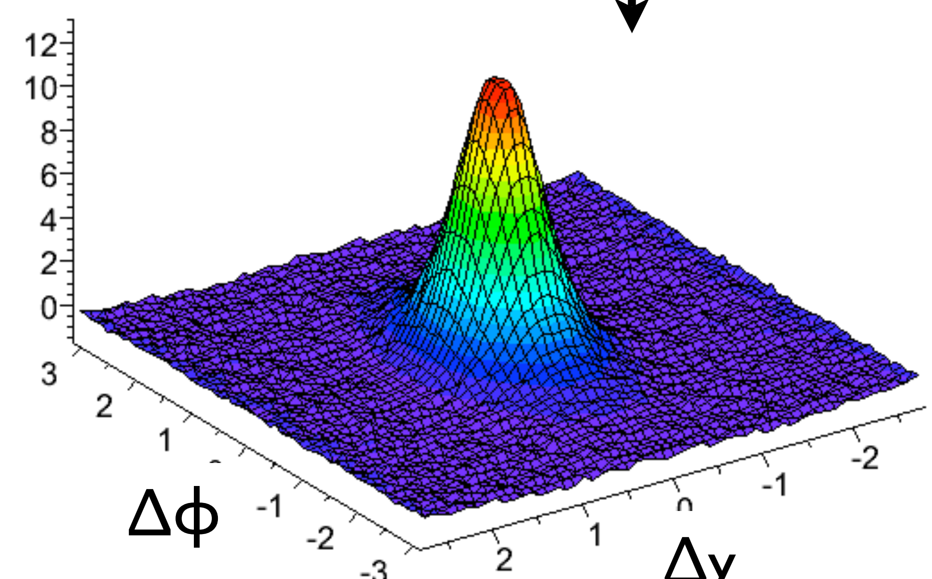
$\tau_{decay} - \tau_0 = 1 fm$ →



$\tau_{decay} - \tau_0 = 1.5 fm$ →



$\tau_{decay} - \tau_0 = 3 fm$



$\tau_{decay} - \tau_0 = 9 fm$

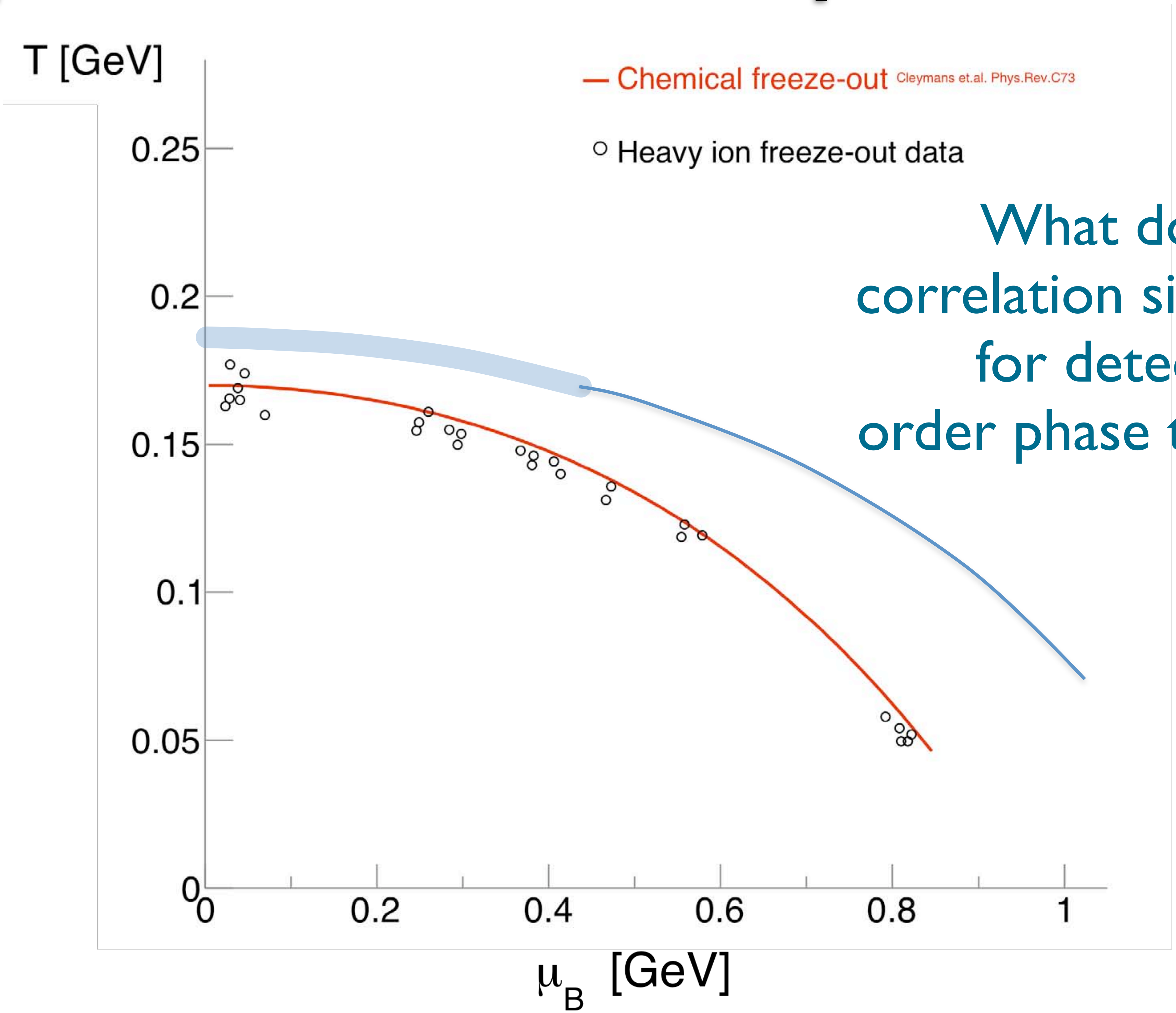
Δy width narrows with τ_{decay}

Δφ width depends on T & ⟨β⟩ : both depend on τ_{decay}

Signatures of transition will be strong if transition is near freeze-out

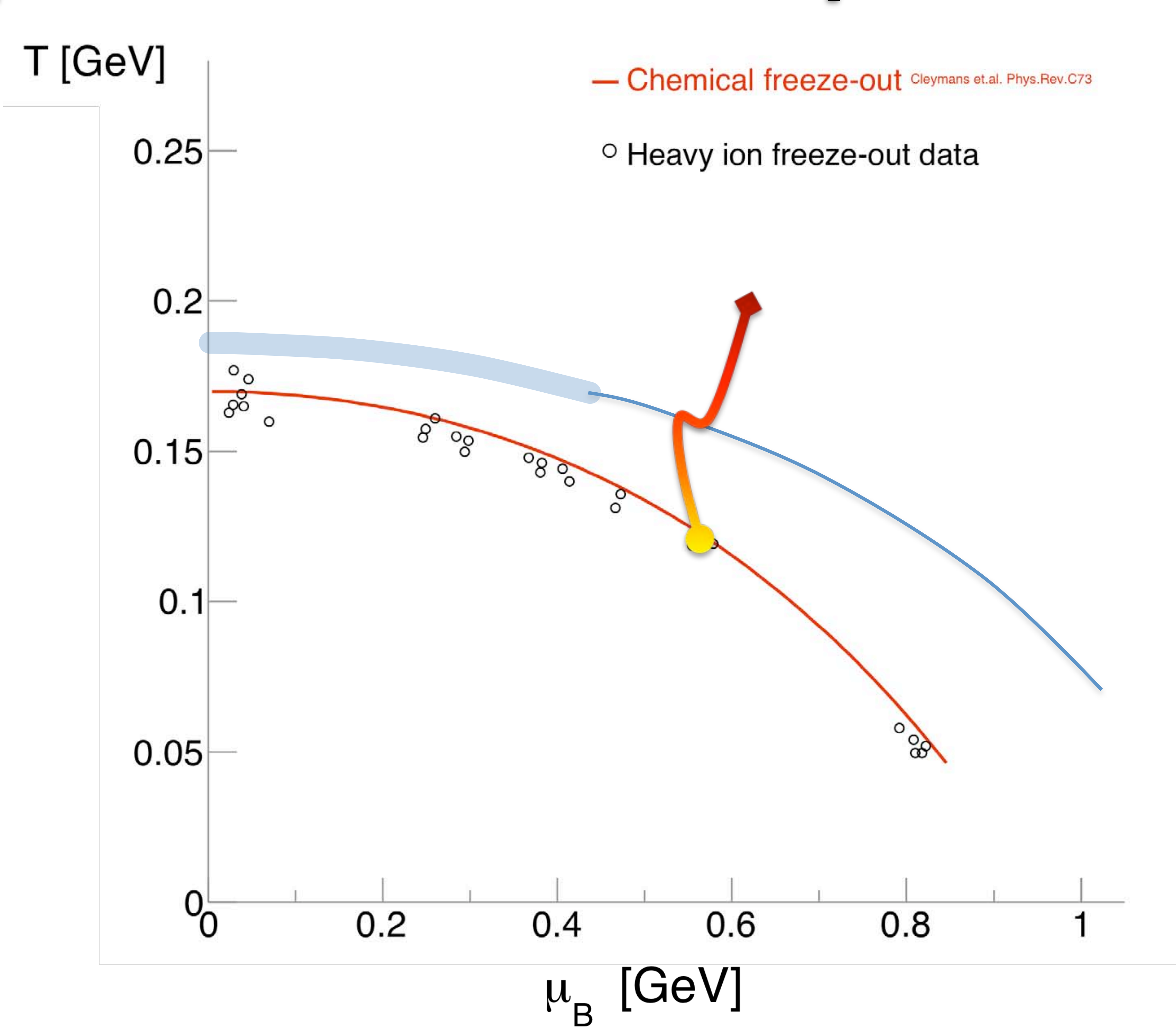
Pocket formula: $\sigma_y = 0.37 + 0.47\tau^{-1.58}$

Implications for Experiments



What does such a correlation signal mean for detecting a 1st order phase transition?

Implications for Experiments



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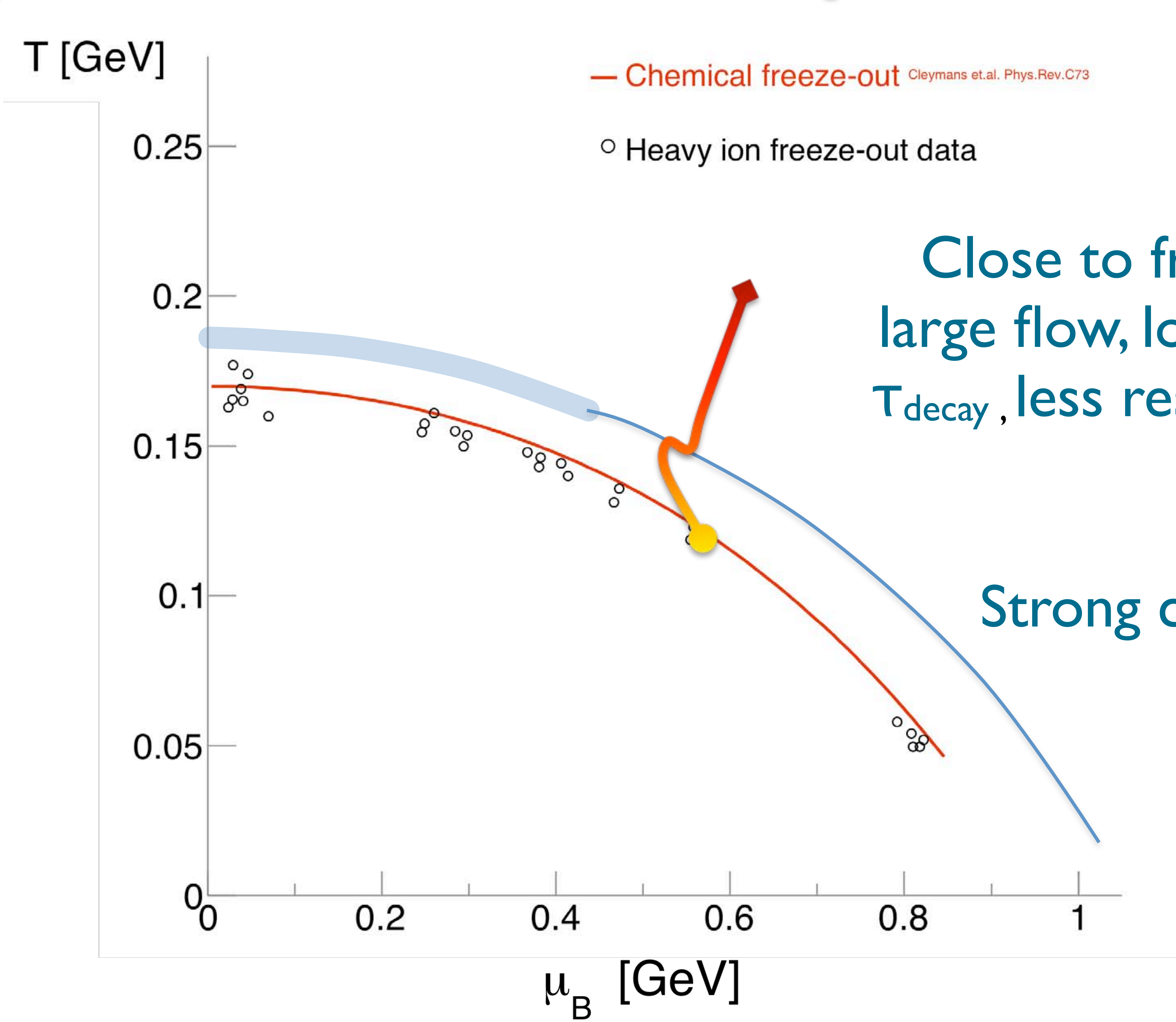
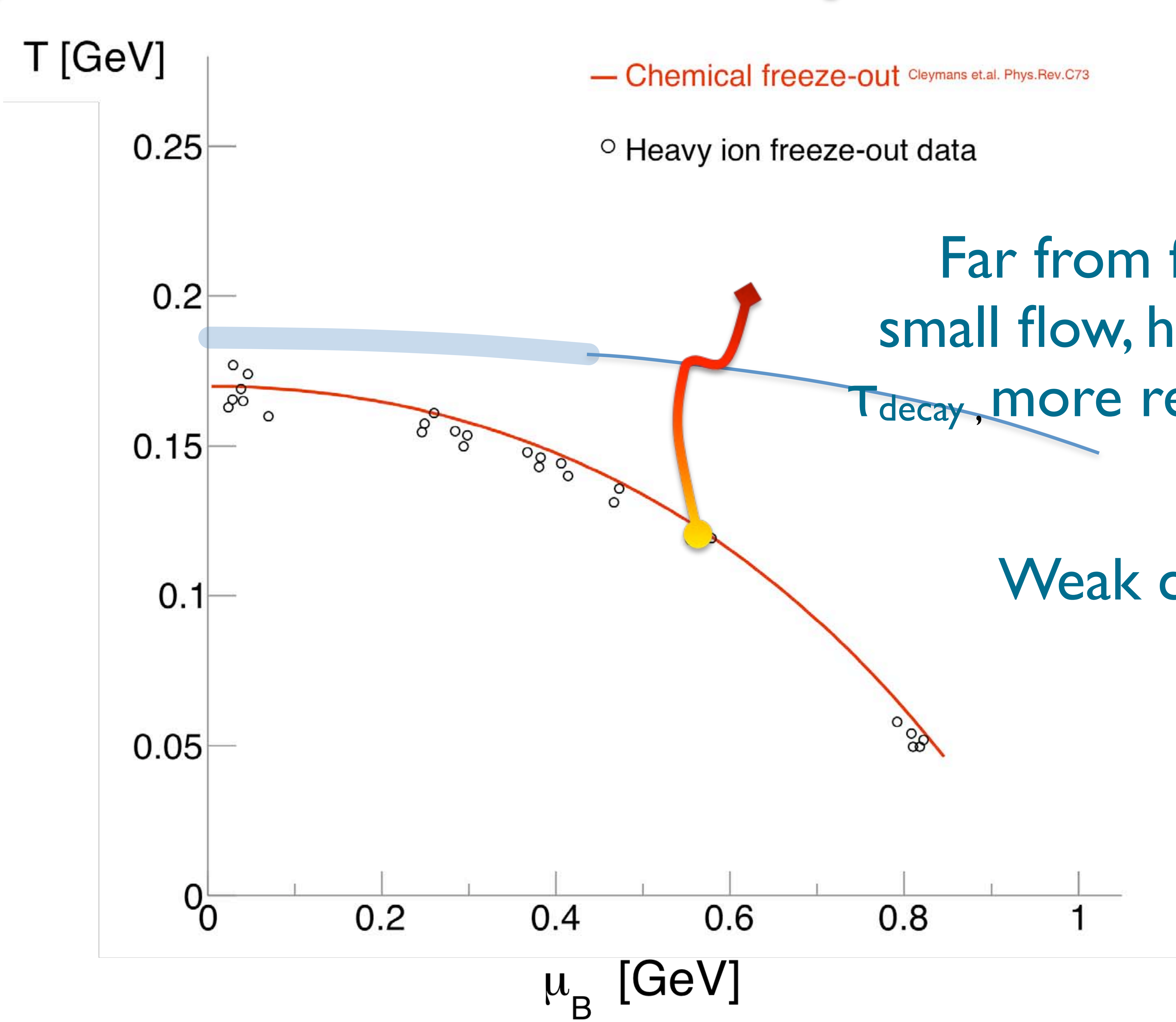


Close to freeze-out: large flow, low T, large τ_{decay}, less rescattering

↓

Strong correlation

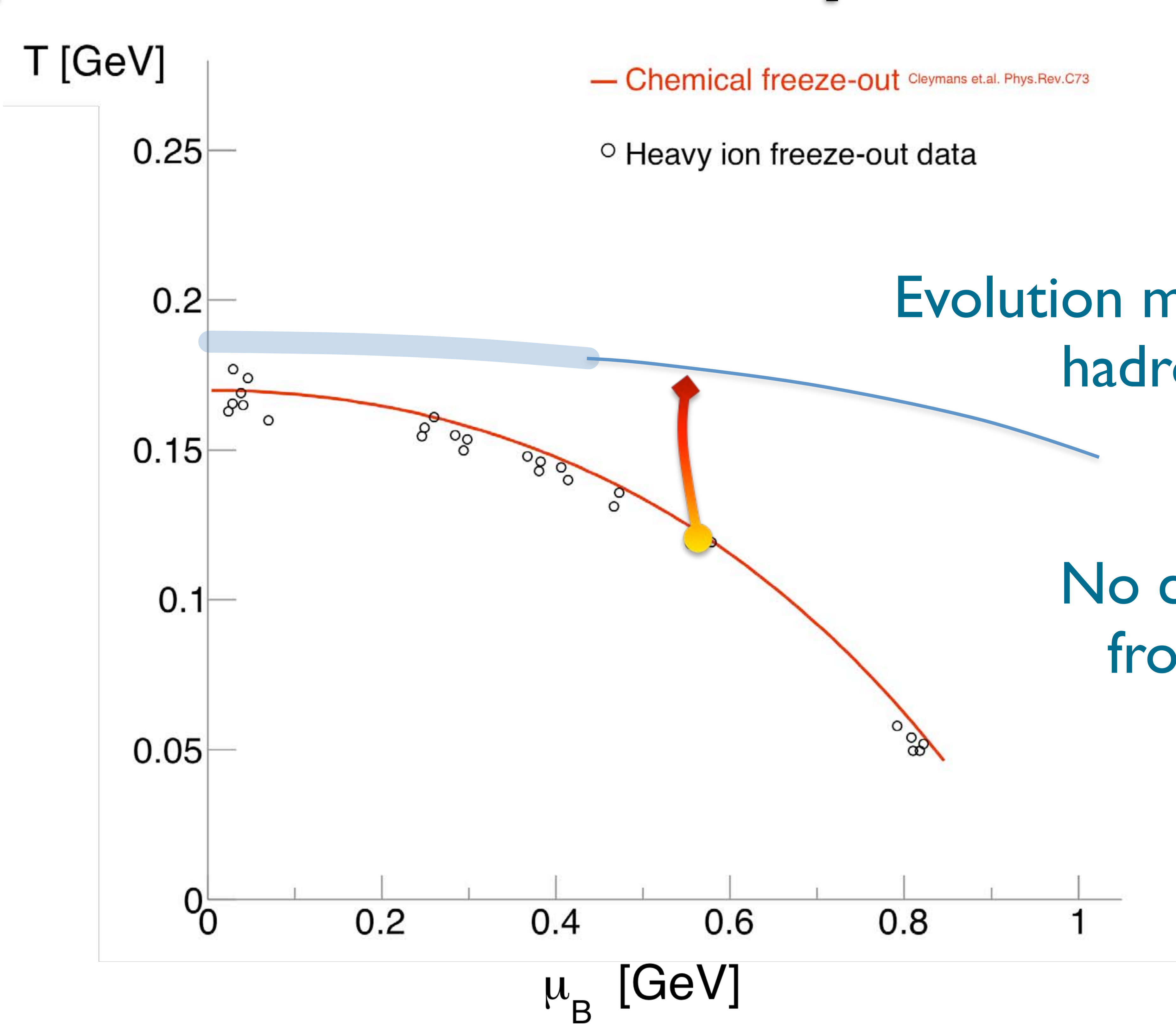
Implications for Experiments



Far from freeze-out: small flow, high T, small τ_{decay}, more rescattering

Weak correlation

Implications for Experiments



Evolution may start in hadronic phase

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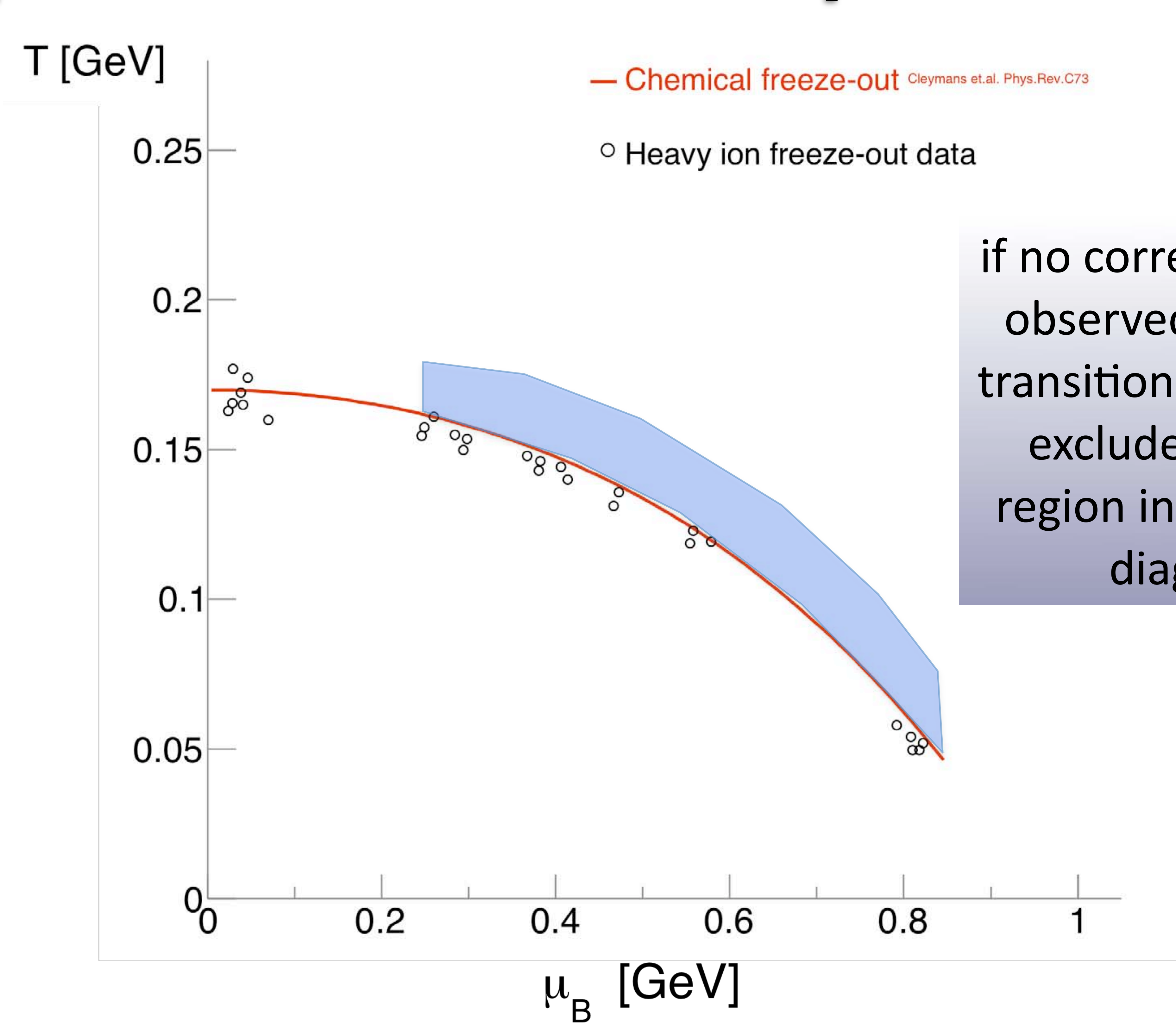
No correlation from bubbles

Implications for Experiments



if no correlations are observed then the transition line can be excluded from a region in the phase diagram

For more accurate exclusion zone: dynamic model needed to relate flow, T, μ_B and time

Summary & Conclusion

A 1st order phase transition will lead to spatial correlations between baryons via bubble nucleation

Flow can translate those correlations to near-side baryon-baryon momentum space correlations; *a smoking gun for 1st order phase transition*

Characteristics of correlations have been estimated for different flow strengths, temperatures and decay times

Lack of signal excludes the presence of a 1st order phase transition within some range: *dynamic model needed for more accurate exclusion region*

*** The End ***